A STUDY OF SURFACE MOTOR UNIT ACTION POTENTIALS IN FIRST DORSAL INTEROSSEUS (FDI) MUSCLE

Ping Zhou, W. Zev Rymer, Nina Suresh & Liqun Zhang

Biomedical Engineering Department, Northwestern University

Rehabilitation Institute of Chicago, Sensory Motor Performance Program, Chicago, IL, USA, 60611

Abstract-**We studied the basic shapes of surface MUAP's of the FDI muscle using a wavelet matching technique. By averaging surface EMG's triggered by the intramuscular EMG, we found the surface MUAP's matched very well with the selected wavelets. It provides us a potential way to quantify the surface EMG by estimating the number of the action potentials contained within it.**

Keywords - **EMG, Surface MUAP, Wavelet**

I. INTRODUCTION

The surface electromyography (sEMG) is the product of a superposition of motor unit action potential (MUAP) trains from active motor units (MUs) having fibers in the vicinity of the recording electrodes. For the intramuscular EMG, recorded MUAP's are often distinct, so it is possible to know the number of the action potentials by counting the action potential spikes. Even at very high force levels, when action potential superposition occurs, we still can estimate the number of action potentials by EMG decomposition techniques, which are designed to allow the separation of overlapped waveforms. [1][2][3][4] etc. Because of large detection surfaces and greater superposition of action potentials, it is hard to estimate the number of the action potentials recorded by the surface EMG. Moreover, due to large detection surfaces and filtering effect of the intervening tissues, the surface MUAP shapes are no longer as distinct as they are when recorded using an intramuscular electrode. So, calculating the number of action potentials present in the surface EMG is inherently more difficult. In spite of these difficulties, such calculations allow an estimate of the total activity in the motoneuron pool. From this, we can calculate muscle force more precisely. In this paper, we seek to study the identification and counting of surface MUAP's using wavelet matching technique.

II. SURFACE MUAP'S AND WAVELETS

EMG signals are composed of different MUAP's. Each displays an impulse property, which means that it changes in a rapid fashion. Due to this property, the EMG signal is well suited to wavelet analysis. The shape of each MUAP is determined by the relative position of the recording electrode and the muscle fibers that belong to the same MU. For different MU's, the muscle fiber arrangements are potentially different.

For a point recording (such as a needle), these differences can be recorded by the electrode, so the recorded MUAP's have various shapes. Minor position changes will cause distinct variations of the recorded intramuscular MUAP shapes. For surface recordings, the detection surface is large and distant from the active MU's. Consequently, differences in muscle fiber arrangements are not as evident. Hopefully, we can use several simple shapes to represent all the MUAPs' basic shapes.

In addition, due to the filtering effects of the volume conductor, different MUAP's detected with surface technique can be treated as dilated and attenuated versions of one (or at least a small number of) basic shapes. MUAP's due to deeper motor units are dilated with respect to those due to more superficial ones. Therefore, the global surface EMG signal can be modeled as the superposition of delayed and scaled versions of several basic components. This leads to the idea of using wavelet technique to analyze surface EMG signal.

Accordingly, different wavelets were chosen to match the shape of the signal detected. In an ideal case, the second order Hermite-Rodriguez (HR) function and first order HR function match very well with a simulated double differential and single differential detected MUAP. [5][6][7] The second order HR function can be used to match the semiwave making up an asymmetric MUAP. [8] Based on this idea, in this study, by analyzing real surface EMG data, we try to find what kinds of wavelets can be employed as basic surface MUAP templates for the First Dorsal Interosseous (FDI) muscle.

III. EXPERIMENTAL SETUP

To minimize noise, a differential detection configuration was employed. Single differential detection is the most commonly used technique. The electrode is Delsys Inc. Single Differential Electrode DE-2.1. It has two parallel detection bars, with each bar 1cm in length and 1mm in width. The inter distance between two bars is 1cm.
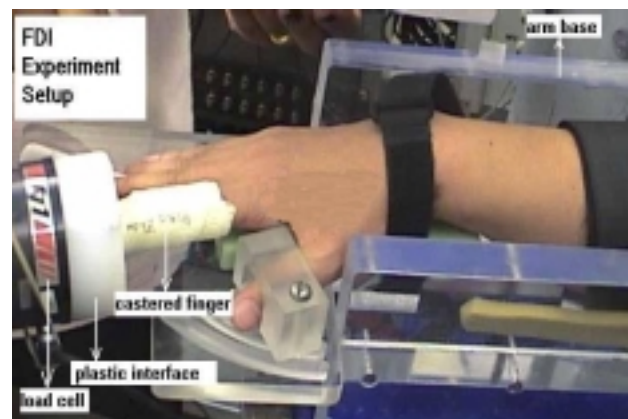

Fig. 1. Experiment setup

11 subjects, 7males, 4 female, aged from 25 to 47, with no signs of neuromuscular disorders, participated in this study. MU's from FDI muscles were investigated. Subjects were

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Abstract

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seated with their forearm resting comfortably on an arm base. The wrist, forearm, three medial fingers and thumb were also secured to the base. The index finger made contact with the load cell via a custom fit ring. (Fig. 1) Subjects were asked to generate a very little isometric force in the FDI muscle. Both surface EMG and fine wire EMG were collected simultaneously. The surface electrode was placed in a similar position in each subject by marking the FDI borders. The surface electrode was positioned between the motor point and the tendon insertion and along the longitudinal midline of the muscle. The longitudinal axis of the electrode was aligned parallel to the length of the muscle fibers.

Before each experiment, we used the electrical stimulation technique to identify the motor point of the FDI muscle. EMG signals are amplified by a gain of 50K (Bagnoli-4 EMG System, Delsys Inc.) with a frequency bandwidth of 20-450Hz for surface EMG and 20-2000Hz for intramuscular EMG. Both surface and intramuscular EMG were displayed on an oscilloscope. The two channels' EMG signals were digitized with a sampling frequency of 5KHz using a data acquisition system(CED1401plus). The single MUAP on surface EMG was characterized by averaging the surface EMG signal triggered by the occurrence of a single MU spike in the intramuscular EMG signal. During this process, we need to carefully check the intramuscular EMG and to discard those signals which contained superimposed potentials. Then we averaged the surface EMG 6ms before and 12ms after the event signals of every MU. (Fig.2) In this way, we can describe the basic surface MUAP templates of the FDI muscle.
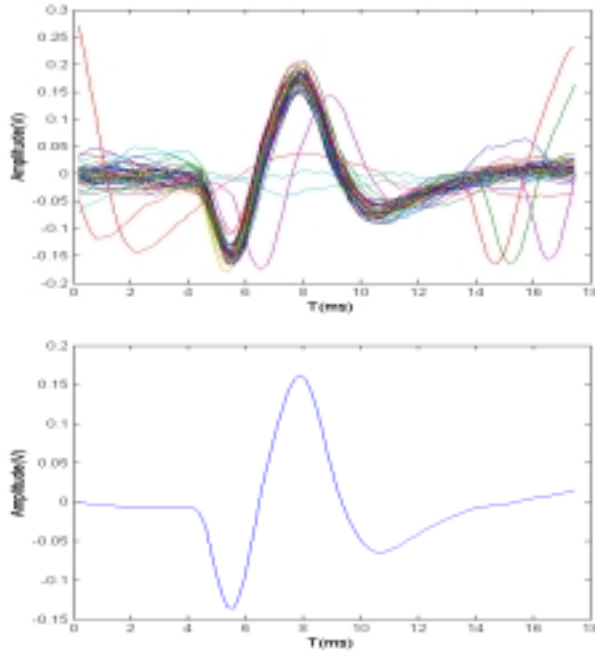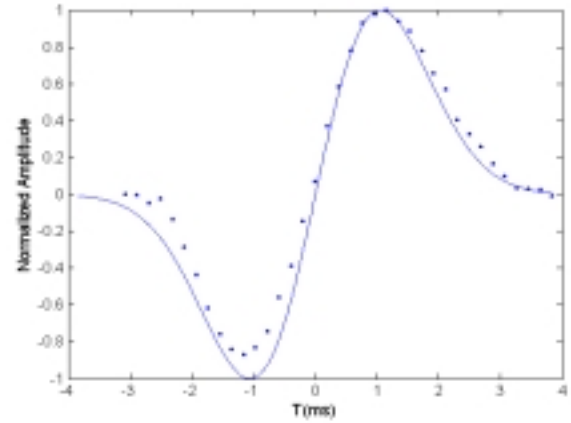
Fig. 2. An example of MUAP's on skin surface (top) and their average (bottom).

IV. RESULT

The experimental result shows that, for one subject, we detect only one surface MUAP template. All the detected surface MUAP's are dilated or attenuated versions of this basic shape.

(a) A MUAP (dotted line) along with the HR1 wavelet (solid line). The two curves are well matched with a scale value λ =7.8.
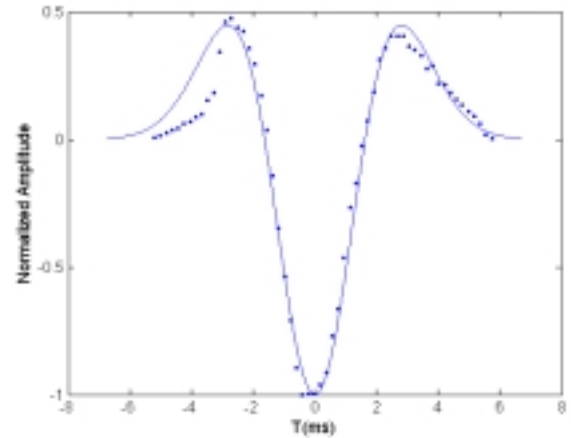
(b) A MUAP (dotted line) along with the HR2 or Mexican Hat wavelet (solid line). The two curves are well matched with a scale value λ =12
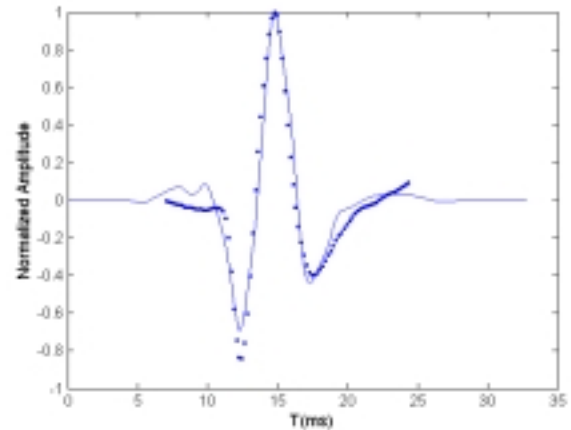
(c) A MUAP (dotted line) along with the Symlet4 wavelet (solid line).

Fig. 3. Detected surface MUAP's (dotted lines) of FDI are shown along with the wavelets (solid line).

For all the 11 subjects, the surface MUAP's for FDI muscle typically showed three phases. We use HR1, HR2 (or

Mexican Hat) and Symlet4 wavelets to represent their basic shapes. HR function of order n is proportional to the n-th derivative of a Gaussian function. Its expression is:

$$HR_{\lambda,n}(t) = \frac{(-1)^n \lambda^n}{\sqrt{2^n n!}} \frac{d^n}{dt^n} \frac{1}{\sqrt{\pi}\lambda} e^{-t^2/\lambda^2} \qquad (1)$$

Accordingly, the expressions of HR function of order 1 (HR1) and 2 (HR2) are:

$$HR_{\lambda,1}(t) = k_1 t e^{-t^2/\lambda^2} \qquad (2)$$

and

$$HR_{\lambda,2}(t) = k_2(1 - \frac{2t^2}{\lambda^2})e^{-t^2/\lambda^2} \qquad (3)$$

where, k_1 and k_2 are normalization factors. Symlet family wavelets are compactly supported orthogonal wavelets. It has no explicit expression.

If we carefully choose the scale value, the detected surface MUAP's are well matched with these three wavelets. Fig. 3 shows an example of this matching.

V. DISSCUSSION

There are many factors affecting the shape of surface MUAP, including the electrode configuration, location and orientation, the architecture of the muscle and tissues between the active fibers and the electrode and some physiological and biochemical events. For example, the signal detected with a differential technique is influenced by the angle between the electrode direction and the signal propagation direction. If they are not parallel each other, we will get an asymmetric shape. From this point of view, the results we get are the representations of the overall effect of all relevant factors affecting the shape of surface MUAP. But it should be acknowledged that the three wavelets are only applicable for the specific electrode DE-2.1, and only for the FDI muscle. If we change the electrode configuration or study some different muscle, we may well extract different surface MUAP wavelets.

Furthermore, the FDI is a small muscle. Compared with the muscle size, the detection surface of the electrode we use is relatively large. In addition, for the FDI muscle, large and small motor units are uniformly distributed throughout the muscle, and the muscle fibers making up a motor unit may be widely dispersed. [9] This explains why we only extract just one template for one subject. All the differences among detected MU's are obscured compared with the large detection surface.

During the experiment, the FDI muscles contraction was set at a very low force level. At higher forces, new MU's will be recruited. If we study the surface MUAP templates recruited at a higher force level. Hopefully, we still can use the same wavelet to represent them.

Because of the property of the EMG signal, it is potentially suitable for time frequency analysis. The Wavelet Transform (WT) is a linear time frequency method towards the multi-resolution analysis of the signal. It produces outputs similar in theory to those of matched filters. [10] In order to

maximize the output at the location and scale of a signal of interest, it is necessary for the wavelet used in the multiresolution analysis to "match" the signal of interest. For the surface EMG signals, if we choose the wavelets which match the detected MUAP's, we can get the maximum energy concentration. Even at low signal-to-noise ratio (SNR) or at
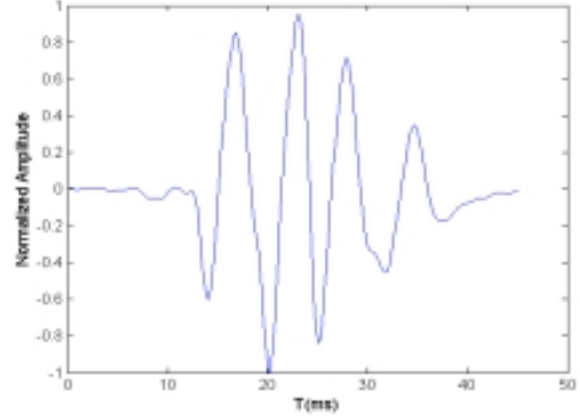
(a) A sample of superposed EMG signal
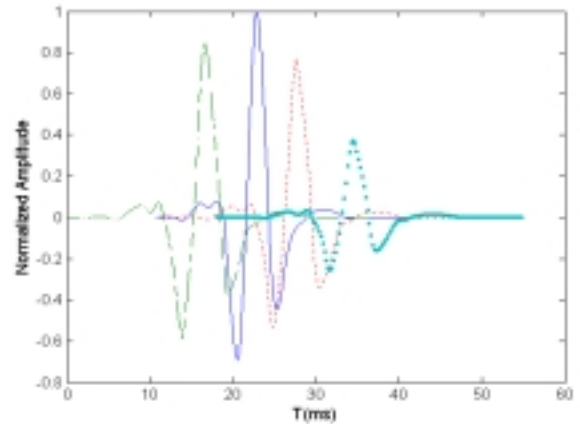
(b) Decompose (a) into 4 Symlet family wavelets at different scales and locations
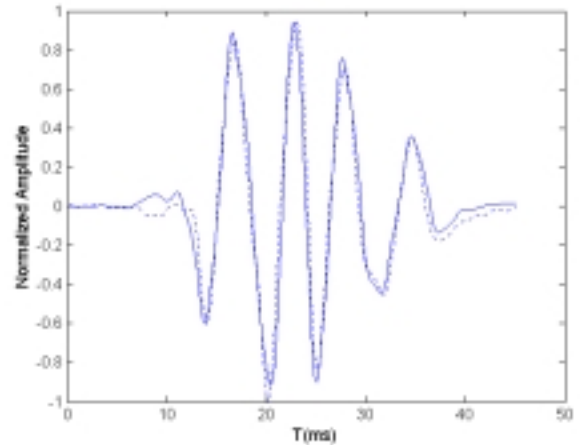
(c) The superposition of four wavelets (solid line) along with the superposed EMG (dotted line)

Fig. 4. An example of estimating the MUAP's contained in sEMG using wavelet matching technique

partially MUAP superposition levels, the individual MUAP can still be identified using matched WT.

A considerable advance has been made in quantitative EMG, mainly for intramuscular EMG's. Pioneering work was done by Buchthal and his colleagues on MUAP parameters. [11]. But this analysis can only be performed at very weak effort. At high force levels, the individual MUAP can no longer be identified and methods are required to quantify the interference patterns.

Several attempts have been made to obtain reliable methods for analyzing the interference patterns, including power spectrum analysis, analysis of zero crossings per unit time, analysis of integrated electrical activity as well as turns amplitude (T&A) analysis and its modifications. [12][13][14] etc. For intramuscular EMG, because of the tiny detection point, the number of the detected MU's is small. Even at high force level, we can estimate the number of the action potentials by decomposition of the interference pattern.

As for surface EMG, due to the high superposition of the action potentials, it is very difficult to decompose interference patterns. Usually, we use Root Mean Square (RMS) value or mean rectified amplitude to analyze surface EMG. It is generally agreed that when rectified and sufficiently smoothed, the amplitude of the surface EMG of a muscle is qualitatively related to the amount of force muscle generates. So, we can use RMS value to estimate the force. However, an accurate quantitative relationship remains elusive.

Surface EMG is noninvasive, and convenient. More important, surface EMG represents the total activity of the motoneuron pool and it is more appropriate for the neuromuscular system study. If we can estimate the number of the action potentials contained within the surface EMG signal, it will give us a potential way to quantitatively analyze surface EMG signals, which should be more appropriate. The result of our experiment shows it is feasible. Because if we can use a small number of wavelets to represent all the possible action potentials recorded by the surface electrode, estimating the number of the action potentials will convert to a pattern recognition problem. We can estimate the number of contained action potentials by extracting an already known pattern from it. Fig. 4 shows an example of how a superimposed signal (Fig. 4, a) can be decomposed into 4 Symlet family wavelets at 4 different scales and locations. (Fig. 4, b) It is clear that the summation of the 4 wavelets match very well with the superimposed EMG (Fig. 4, c), which shows the decomposition is reasonable.

VI. CONCLUSION

Due to the large detection areas of the surface electrodes and the filtering effects of the volume conductor, it is possible to use a small number of wavelets to represent all the possible surface MUAP's. This gives us a potential way to estimate the force muscle generates and study the motoneuron pool activity by estimating the number of the action potentials contained within surface EMG.

REFERENCES

[1] Renold S. Lefever and Carlo J. Deluca, "A Procedure for Decomposing the Myoelectric Signal Into It's Constituent Action Potentials---Part 1, Technique, Theory, and Implementation," *IEEE Trans. on Biomedical Engineering,* vol.29, No.3, pp149-157, 1982.

[2] K. C. McGill, K. L. Cummins and L. J. Dorfman, "Automatic Decomposition of the Clinical Electromyogram," *IEEE Trans. on Biomedical Engineering,* vol.32, No.7, pp470-477, 1985.

[3] H. Etawil and D. Stashuk, "Resolving Superimposed Motor Unit Action Potentials," *Med. & Biol. Eng. & Comput,,* vol.34, pp33-40, 1996.

[4] Fang, J., Agarwal G. and Shahani B., "Decomposition of Multiunit Electromyographic Signals," *IEEE Trans. on Biomedical Engineering,* vol.46, No.6, pp685-697, 1999.

[5] G. Olmo, F. Laterza, "Matched Wavelet Analysis of Single Differential EMG Signals," *Proceedings of SPIE Congress on Wavelet Applications in Signal and Image* Processing V, San Diego, CA, USA, vol.3169, pp579-586, 1999.

[6] Dario Farina, Elena Fortunato and Roberto Merletti, "Noninvasive Estimation of Motor Unit Conduction Velocity Distribution Using Linear Electrode Arrays," *IEEE Trans. on Biomedical Engineering,* vol.47, No.3, pp380-388, 2000.

[7] F. Laterza and G. Olmo "Analysis of EMG Signals by Means of the Matched Wavelet Transform," *Electronics Letters,* vol.33, No.5, pp357-359, 1996.

[8] G. Olmo, F. Laterza and L. Lo Presti, "Matched Wavelet Approach in Stretching Analysis of Electrically Evoked Surface EMG Signal," *Signal Processing,* vol.80, pp671-684, 2000.

[9] H. S. Milner-Brown and R. B. Stein, "The Relationship Between The Surface Electromyography and Muscular Force," *J. Physiol.,* vol.246, pp549-569, 1975.

[10] Szu. H., Sheng Y. and Chen. J., "The Wavelet Transform as A Bank of Matched Filters," *Appl. Opt.*, vol.31, pp3267-3277, 1992.

[11] Buchthal F., Guld C. and Rosenfalck P., "Action Potential Parameters in Normal Human Muscle and Their Dependence on Physical Parameters," *Acta. Physiol. Scand.,* vol.30, pp200-218, 1954.

[12] Fuglsang-Frederiksen, "Interference EMG Analysis," in *Computer-Aided Electromyography and Expert System*, vol. 2, J. E. Desmedt, Eds. Amsterdam - New York - Oxford: Elsevier, 1989, pp161-179.

[13] R. G. Willison, "Analysis of Electrically Activity and Dystrophic Muscle in Man," *J. Neurosurg. Psychiat.,* vol.27, pp386-394, 1964.

[14] A. L. Rose and R. G. Willison, "Quantitative Electromyography Using Automatic Analysis: Studies in Healthy Subjects and Patients with Primary Muscle Disease," *J. Neurosurg. Psychiat.,* vol.30, pp403-410, 1967.